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DATA REQUIREMENTS FOR AVAILABILITY BASED SPARING IN THE U. S. MARINE CORPS

by

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Availability based sparing was prescribed for use in all the military services by the DoD in 1985. Since then, the Army, Navy, and Air Force have all implemented, in varying degrees, availability based models; however, the Marine Corps has made little progress. Recent studies by the Center for Naval Analyses (CNA) suggest that the Marine Corps has a difficult road ahead as it seeks to implement such models. Among the most demanding challenges identified are the requirements for more detailed and accurate data. While the CNA studies examined a full-scale implementation of availability based sparing, we argue that the Marine Corps can, and indeed should implement such models on a limited scale with data from current information systems. Because availability based sparing models have different data requirements than the Marine Corps demand configured supply (SASSY) and maintenance (MIMMS) logistical information systems, we recommend changes to these systems in order to implement a full-scale availability based model.

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DATA REQUIREMENTS FOR AVAILABILITY BASED SPARING IN THE U. S. MARINE CORPS

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ABSTRACT

Availability based sparing was prescribed for use in all the military services by the DoD in 1985. Since then, the Army, Navy, and Air Force have all implemented, in varying degrees, availability based models; however, the Marine Corps has made little progress. Recent studies by the Center for Naval Analyses (CNA) suggest that the Marine Corps has a difficult road ahead as it seeks to implement such models. Among the most demanding challenges are the requirements for more detailed and accurate data. While the CNA studies examined a full-scale implementation of availability based sparing, we argue that the Marine Corps can, and indeed should implement such models on a limited scale with data from current information systems. Because availability based sparing models have different data requirements than the Marine Corps demand configured supply (SASSY) and maintenance (MIMMS) logistical information systems, we recommend changes to these systems in order to implement a full-scale availability based model.

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I. IMPLEMENTING AVAILABILITY-BASED SPARING IN THE MARINE CORPS

Sparing is the term used to describe the range and depth of inventory determined for a weapon system. Availability-based sparing was prescribed for use in all military services by the DoD in 1985 [Ref. 1]. Since then, the Army, Navy, and Air Force have all implemented, in varying degrees, availability-based models. To date, however, the Marine Corps has made little progress. Recent studies by the Center for Naval Analyses (CNA) [Ref. 1-5] suggest that the Marine Corps has a difficult road ahead as it seeks to implement such models. Among the most demanding challenges is the requirement for data, both more detailed and more accurate than is currently captured by Marine Corps logistical information systems.

While the CNA studies examined a full-scale implementation of availability-based sparing, we show that the Marine Corps can, and indeed should, implement availability-based models on a limited scale with data available from current information systems. We describe in detail the data requirements for such models, and demonstrate that the Marine Corps already captures the data necessary for their basic implementations.

A. AVAILABILITY-BASED SPARING

Availability-based sparing models recommend parts on a system basis, according to which provide the greatest contribution to a system's availability for use. Equipment readiness and investment goals are input parameters to the decision making process. In contrast, *demand-based* sparing models recommend parts on an item by item basis, according to historical demand. Equipment readiness and investment are uncontrolled outputs.

As commonly used *availability-based sparing* and *readiness-based sparing* are synonymous. We use the term *availability-based sparing* to prevent confusion with specific implementations of the methodology under the name *readiness based sparing* by the Services. This work focuses on the fundamental data requirements of the methodology, not on a specific implementation.

As noted above, availability-based sparing is not new to the Military Services. The DoD's Secondary Item Weapon System Management (SIWSM) concept called for its use in the middle 1980s. This directive was designed to achieve efficiencies in programming limited investment funds by basing sparing requirements on weapon system readiness goals rather than inventory demand [Ref. 1]. It was issued at about the same time that GAO was conducting critical audits of the DoD's inventory management, specifically citing that the inventory was oversized. GAO had identified the DoD inventory as one of the Government's high-risk areas because of vulnerabilities to waste, fraud, abuse, and mismanagement [Ref. 6].

The Air Force, Navy, and Army responded by introducing availability-based models into their requirements determination process and showed benefits soon thereafter. Examples include the Navy's test implementation of availability-based sparing on the USS America that resulted in a $33 million dollar reduction in inventory while maintaining readiness [Ref. 7]. The Army's test implementation of availability-based sparing at the National Training Center and 5th Infantry Division resulted in reduction in inventory investment, improvements to equipment readiness, and decrease in the weight and volume of the parts block allowing for greater mobility for deployments [Ref. 8].

The Marine Corps has been slow to implement availability-based sparing models, but for the most part, has avoided the scrutiny of the GAO audits because its inventory is much smaller than those found in the other Services (see Table 1). Even so, the Marine Corps recognizes the need to migrate to availability-based sparing, as shown by recently commissioned CNA studies, because its inventory managers must make the cost readiness trade-off decisions allowed by such models. Defense budget reductions in recent years now make such decisions imperative.

COMPONENT	AMOUNT (IN BILLIONS)		% OF TOTAL
	1996 Dollars	1995 Dollars	
Air Force	$29.34	$28.75	42.9%
Navy	$18.34	$17.97	26.8%
Army	$10.77	$10.56	15.7%
DLA	$ 9.53	$ 9.41	13.9%
Marine Corps	$ 0.47	$ 0.52	0.7%
Total	$68.45	$67.08	100.0

Table 1. Value of Secondary Item Inventory as of September 30,1996 [Ref. 9]

B. PURPOSE & METHODOLOGY

Ivancovich et al. [Ref. 1] state that the Marine Corps' maintenance and supply information is neither detailed nor accurate enough to support a move to availability based sparing at the present time. This is largely the result of the Marine Corps supply (SASSY)[1] and maintenance (MIMMS)[2] logistical information systems being configured to support demand-based sparing. Even so, these systems capture enough data to implement availability-based sparing on a limited scale. We describe the data requirements for Marine Corps logistical information systems to facilitate implementing availability-based sparing models. We answer the following research questions in doing so:

1. What are the data, models, and information system requirements necessary to implement an availability methodology; and what are the requirements for establishing and maintaining them?
2. What availability-based sparing models are currently available for potential use in the Marine Corps?
3. How well might existing logistical information systems support a new availability methodology

For each question we limit our scope to "Class IX" (of ten classes of supply) repair parts at the retail-intermediate inventory level.[3]

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[1] Supported Activity Supply System (SASSY) is the supply management system that provides supply functions, such as stock replenishment, requirements determination, receipts, inventory, stock control and asset visibility.

[2] Marine Corps Integrated Maintenance Management System (MIMMS) provides reporting of active maintenance and repair parts information.

[3] There are three levels of inventory management in the Marine Corps: wholesale, retail-intermediate, and retail- consumer. The SASSY Management Unit (SMU) is the Class IX retail-intermediate inventory provider for the Marine Corps.

In addressing the first question we review how Ivancovich et al. [Ref. 1] suggest to implement availability-based sparing through the Multi-Indenture, Multi-Echelon (MIME) model. We use MIME as a baseline for availability-based sparing data requirements, but disregard the multi-echelon data elements because we are only concerned with a single echelon of supply- the retail-intermediate echelon of supply, the SMU. In the following chapter, we compare and contrast demand-based and availability-based sparing models, identify the strengths of each model, and suggest how they can be used together to form an effective inventory policy.

To address the second question we examine four availability-based sparing implementations: the Navy's Readiness Based Sparing (RBS) Workstation program; the Navy's Aviation Retail Requirements Oriented to Weapon Replaceable Assemblies (ARROWS) program; the Army's Optimum Stock Requirements Analysis Program (OSRAP); and finally, a commercial spares optimization program called VMETRIC. The creator of VMETRIC, Dr. Craig Sherbrooke, created the METRIC algorithms that are used in all the availability-based sparing applications we encountered. We narrow our scope to the two retail level applications, OSRAP and ARROWS, which we contrast in Chapter IV. We then suggest opportunities for their applicability to the Marine Corps.

In addressing the third question, we demonstrate that while existing systems support a limited implementation of availability-based sparing, additional data is required for optimal use, specifically indenture structure and operational failure rates.

Consequently, we recommend changes to current Marine Corps logistical information systems in Chapter V.

II. DEMAND-BASED AND AVAILABILITY-BASED SPARING

Success in Battle is not a function of how many show up, but who they are.

- General Robert H Barrow, USMC – 2 June 1981 [Ref. 10]

A Class IX repair parts block is an inventory of repair parts maintained to ensure an operational unit's equipment readiness. Repair parts can be classified as either *reparables* or *consumables*. As the name implies, reparables are those parts that maintenance activities can return to service through repair. Consumables are disposed of upon failure. Consumables can be further designated as *critical consumables* or *piece parts.* The difference is that the failure of a critical consumable renders the associated end item inoperative, whereas failure of a piece part does not.

Sparing models assist the inventory manager in determining the range and depth of these parts. The term *range* is used to describe the number of different line items held in inventory. The term *depth* is used to describe the quantity of each line item held in inventory. Demand-based sparing models recommend parts on an item by item basis, according to historical demand. On the other hand availability-based sparing models recommend parts on a system basis, according to which provide the greatest contribution to a system's availability.

A. DEMAND-BASED SPARING

Demand-based inventory models have been in existence for decades [Ref. 11]. The underlying theory of demand-based sparing is the Economic Order Quantity

(EOQ) model, which optimizes inventory levels by balancing holding and ordering costs. In contrast, the Marine Corps uses demand-based sparing with inventory levels based on days of supply (DOS). The Marine Corps uses DOS because it lends itself to a readiness posture, in the sense that a unit could be expected to sustain itself for this long if called to action. This motivation is foreign to EOQ and commercial businesses, however.

The Marine Corps captures historical demand and translates it into demand per day. Components of this DOS methodology include a 60-day operating level (OL), a 30-day safety level (SL), and an actual order ship time (OST) level. Reparable parts levels also include an actual Repair Cycle Level. The range of stock is determined by frequency of demand, while depth of stock is determined by quantity of demand. [Ref. 12]

The Marines Corps' primary criteria for determining the range of stock is based on a series of combat essentiality codes (CEC). CECs are divided into the following classifications:

CEC	Definition
0	Non-Combat Essential End-item End-items of equipment that do not fit the definition of code 1 items.
1	Combat Essential End-item End-items of equipment whose availability in a combat ready condition is essential for execution of the combat and training mission of command.
2	Non-critical Repair Part Repair parts whose failure in the end-item will not render it inoperative or reduce its effectiveness below the minimum acceptable level of efficiency, which do not fit the definition of code 3 or 4 items
3	Critical Item/Repair Part for Health and Safety of Personnel Those items that are required for the health and safety of personnel, and which do not fit the definition of code 5 or 6 items
4	Critical Item/Repair Part for State and Local Laws Those items that are required to conform with state of local laws, and which do not fir the definition of code 5 or 6 items.
5	Critical Repair Part to a Combat Essential End-item Repair parts whose failure in a combat essential end-item will render it inoperative or reduce its effectiveness below the minimum acceptable level of efficiency
6	Critical Repair Part to a Non-Combat Essential End-item Repair parts whose failure in a non-combat essential end-item will render it inoperative or reduce its effectiveness below the minimum acceptable level of efficiency

Once an item has been selected for stock, its depth must be determined. One of the principal tools for managing the depth of stock is the requisitioning objective/reorder point (RO/ROP). RO/ROP is principally derived from OL, SL, and OST authorizations. Specifically, RO is the sum of the OL, SL, and OST level. The ROP is the sum of the SL and OST level. The RO and ROP serve to systematically advise the inventory manager when and how much to invest. Stock is ordered when the ROP is reached, and is ordered up to the level of RO. [Ref. 12]

1. An Items Approach to Inventory

Demand-based sparing uses what Sherbrooke [Ref. 13] calls an *item approach* to stocking decisions, in which the decision to stock an item is made independently of decisions to stock other items. One disadvantage of an item approach is that equipment availability and investment are outputs, as opposed to being targeted inputs to the sparing model.

By using an item approach, Marine Corps inventory managers do not have the benefit of decision support tools to make analytical cost-readiness tradeoffs. For example, the total number of ROs generated from the demand-based sparing model may call for stockage of $300,000 in parts, but there may only be $100,000 to spend, with no analytical method for prioritizing the available investment. The inventory manager is therefore left to determine adjustments based solely on experience and subjective decision making techniques, the true effectiveness of which is unknown. Additionally, even if the inventory manager had the $300,000 to invest, the demand-based sparing model does not relate inventory investment to the readiness of the equipment being supported. Consequently, the inventory manager could purchase all the parts recommended by the demand-based sparing model only to discover that critical weapons systems still do not meet their readiness objectives.

B. AVAILABILITY-BASED SPARING

Availability-based sparing is a *system approach* to inventory modeling that determines the system cost-effectiveness of stock decisions. Unlike the item approach, the system approach uses equipment availability and investment as input parameters to the decision making process. Consequently, the system approach is able to answer questions such as, "What spare parts do I need to carry to ensure that at least 90% of my tanks will be available?" and "How much will it cost to achieve 95% availability, and which additional parts are required?"

The system approach answers these questions by providing a weapon system availability-cost curve like the one shown in Figure 1. The curve represents the dollar cost of incremental changes in availability. The curve shows that with an investment of $65,508, 76% availability can be achieved. To achieve 90% availability an investment of $289,969 would be required. Points above the curve are not attainable and points below the curve represent an inefficient allocation of resources [Ref 13]. Note that the curve reflects diminishing returns, in that at successive readiness levels, the incremental cost of additional availability increases. Thus, the decision-maker can choose the efficient mix of stock, represented as a point on the curve, to best satisfy availability requirements within budget restrictions.

For availability-based sparing, parts within a modeled system are compared against each other by demand, price, and criticality, and spares are selected to meet the availability goal for the system. Therefore, there is no set demand threshold that a repair part must meet to be eligible for stocking. The combination of demand and price can be used to determine the order in which spares are selected, and the availability goal determines the total amount of spares selected.

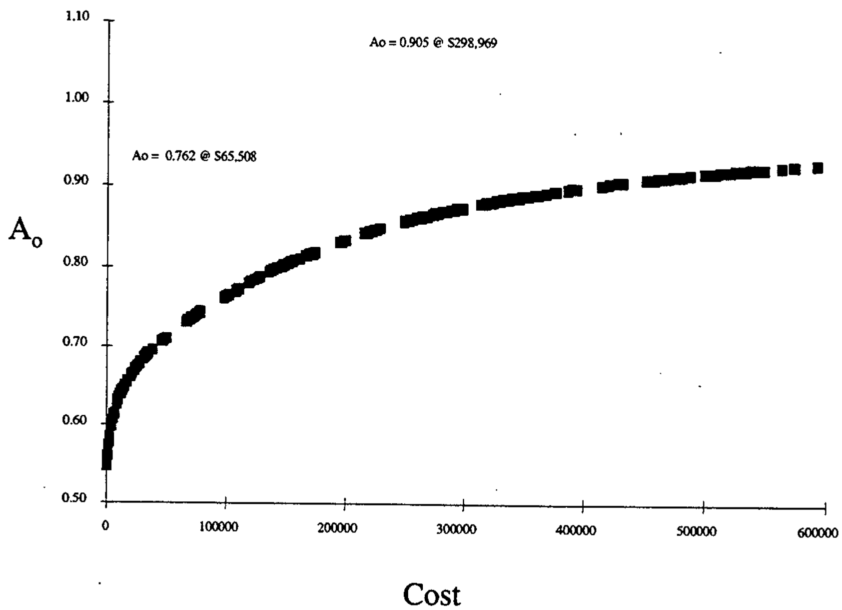

Figure 1. Availability-Cost Curve

1. Operational Availability (A_o)

Availability-based models maximize the probability that the system is ready to perform its intended function in its operational environment. Operational Availability (A_o) is expressed in terms of the percentage of time that a system is capable of performing its intended function as shown in the following equation:

$$A_o = \frac{MTBF}{MTBF + MDT} .$$

Mean Time Between Failure (MTBF) is a measure of system reliability. Mean Downtime (MDT) represents the time a system is unavailable to perform its intended function due to active repair time and logistics delay. MDT can be further decomposed into maintainability and supportability parameters, Mean Time to Repair (MTTR) and Mean Logistics Delay Time (MLDT) respectively. MTTR includes the time to fault isolate and actively repair a system. MLDT represents administrative delays from logistics elements such as supply support, maintenance planning, technical data, and training. By replacing MDT with these components MTTR and MLDT, the expression becomes

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT} \ .$$

Therefore, A_o can be expressed in terms of a system's reliability (MTBF), maintainability (MTTR), and supportability (MLDT). Reliability is a function of systems design parameters; supportability is a function of the logistics environment provided for the system; maintainability is a function of both the system's design parameters and the logistics environment provided for the system. [Ref. 11]

2. Operational Availability Policy

Operational availability can be used to establish efficient inventory policy. Sherbrooke [Ref. 13] proves mathematically that minimizing the sum of expected backorders is equivalent to maximizing operational availability given the following assumptions:

- for a stock level s, a reorder or repair of one unit is initiated whenever the level falls to $s-1$,
- the failure of a single item makes the end-item unavailable, and
- there are no cannibalizations.

The first assumption works well for reparables in the Marine Corps. When a reparable is issued, a backorder for a replacement is immediately established. However, consumables are not ordered after each issue; rather, they are ordered when the ROP is reached. Sherbrooke suggests how the model can be adjusted to calculate RO and ROP for consumables by using expected backorders for a particular item and location as a constraint. With this, it is possible to calculate optimal RO and ROP values. [Ref. 13]

The second assumption is only realistic for repair parts deemed critical. For example, the failure of a piece part such as a door handle does not render a vehicle unavailable. The final assumption coincides with the current policy of not allowing cannibalizations in peacetime operational conditions. The term *cannibalization* refers obtaining a repair part from an end item instead of normal supply sources. Because of these factors, availability-based sparing is better suited for decision making pertaining to stocking reparables and critical consumables whereas demand-based sparing is better suited for piece parts.

3. Indenture Structure

Availability-based sparing accounts for the relationship between consumables and reparables when making stocking decisions using an indenture structure. An indenture structure provides a hierarchy of parts in a manner similar to the way a typical organization chart depicts a hierarchy of departments and units in an organization. Lower indenture parts, such as gaskets and spark plugs, are likely to be common items used in several different assemblies and items higher up the indenture hierarchy (called *parents*). Clearly, a lower indenture part costs less than its parent. Because of the relatively low cost, inventory managers face incentives to stock lower indenture parts rather than their higher-indenture parents. On the other hand, when an item fails, it takes more time and expertise to diagnose and replace the lower indenture items responsible for the failure than are required for whole assemblies or parent items higher up the indenture. This extra time translates into longer system downtime. For this reason, the inventory manager faces a competing incentive to stock higher-indenture items. Availability-based models balance these competing objectives and assist the inventory manager in making stocking decisions. [Ref 13]

C. HOW AVAILABILITY- AND DEMAND-BASED SPARING WORK TOGETHER

Availability-based sparing is applicable to those reparable and critical consumable parts that contribute to the availability of an end item (e.g., a tank, truck or aircraft). The interrelationship between critical consumables and reparables is accounted for to provide optimal stocking decisions. However, data requirements for availability-based sparing are more complicated, time consuming, and expensive than the requirements of demand-based sparing. Specifically, weapons system data is required in addition to technical, failure rate, and pipeline data. Fortunately, some inventory decisions offer greater potential to benefit from availability-based sparing than others. For example, it is only necessary to collect weapon system data on repair parts, meaning both reparables and critical consumables that contribute to a weapons system's availability. It is not necessary to collect weapon system data on the vast volume of piece parts.

Historically, budgeting for consumables (critical consumables and piece parts) and reparables have been performed separately, their respective data has been maintained on different accounting records, and the items have been procured in isolation of each other. However, the funding source for reparables changed in 1994, when it was decentralized from the Marine Corps Logistics Base, Albany to the SMUs. The SMUs are now responsible for funding both consumables and reparables.

Because the requirement to budget and procure consumables and reparables separately no longer exists, the Marine Corps now has an opportunity to facilitate the introduction of availability-based sparing models. To seize this opportunity and budget, manage, and procure consumables and reparables together, the Marine Corps inventory management system needs to incorporate both demand-based and availability-based algorithms.

One important step in this direction would be to consolidate both the budgeting and management of consumables and reparables. For example, by using requirement codes, reparables and critical consumables could be channeled to the availability-based algorithm, and piece parts could be channeled to the demand-based algorithm. This would be a noteworthy improvement over current practice, in which reparables and consumable stocking decisions are made in isolation of each other. Budgeting for a consolidated list of reparables, critical consumables, and piece parts would require the inventory manager to decide what percentage of the budget should be allocated to each group. Budget allocation could be accomplished by graphically comparing points on cost-availability and fill rate curves similar to the one shown in Figure 1. Constructing an optimal allocation requires further research and is beyond the scope of our study.

We stress that one methodology does not replace the other; rather they complement each other. Table 2 summarizes each model's characteristics.

CHARACTERISTICS	DEMAND-BASED SPARING	AVAILABILITY-BASED SPARING
Underlying Theory	Balance order and holding costs	Maximize $A_o \approx$ Minimizing backorders
Application	Low cost, high volume, non-mission critical repair parts	Reparables, critical and high cost consumables
Data Requirements	Simple	Complex
Investment, Readiness	Outputs	Inputs
Performance Measures	Fill Rates	Availability, Cost, Volume

Table 2. Characteristics of Sparing Models

III. DATA REQUIREMENTS FOR AVAILABILITY-BASED SPARING MODELS

It is better to know nothing than know what ain't so.

- Josh Billings [Ref 12]

Ivancovich et al. [Ref. 1] suggested in a recent study that the Marine Corps will have a difficult time migrating to an availability-based methodology, because data contained in its information systems are either not accurate enough or not complete enough to support the more onerous model data requirements. Using Ivancovich's suggested MIME model as a baseline for availability-based sparing data requirements, we define *full* and *limited* implementations of availability-based sparing. A full implementation includes the data requirements to take advantage of all the model's benefits. In the limited implementation, demand failure rates are used instead of operational failure rates and indenture structure is not required. The term *data requirements* refers to those data elements necessary to execute the sparing model.

Table 3 summarizes the data requirements necessary for availability-based sparing. We classify data elements as weapon system data, spares data, failure rate data, pipeline data, and input target data. Weapon system data is the information that relates a repair part to the associated weapon system. Spares data is the technical data such as price, cube, and criticality for each repair part. Pipeline data is the data that measures the time that it takes for a part to be repaired or replenished from the source of supply. Failure rate data is the measurement of how often and under what conditions a repair part fails. Input target data include the decision support parameters that a parts block can be built to. Parameters include availability, fill rate, budget, and weight-cube constraints.

In Table 3, the column labeled "DBS" reflects the Marine Corps' current data requirements for its demand-based sparing model. The column labeled "ABS" reflects data requirements for both a limited and full implementation of availability-based sparing. A limited implementation is identified by all the required data requirements. A full implementation is reflected by both required and optional data requirements. Because the Marine Corps is expeditionary in nature, we discuss the differing data requirements for building deployed parts blocks. The third column labeled "DEPLOY" reflects these data requirements.

A. WEAPON SYSTEM DATA

Weapon system information is not required for demand-based sparing, but is necessary to support availability-based sparing models; however, current Marine Corps logistical information systems do not capture the detailed weapon system data elements necessary to take full advantage of such models. Weapon system data elements include indenture structure, reliability block diagrams, end-item criticality, end-item density, and end-item usage.

	DBS	ABS	DEPLOY
TARGET DATA			
Ao Goal		•	○
Budget Goal		•	
Weight/Cube Goal		•	○
Fill Rate Goal		•	
WEAPON SYSTEM DATA			
Indenture Structure		○	
End-item Criticality		•	○
End-item Usage		○	○
End-item Density		•	•
Reliability Block Diagram		○	
SPARES DATA			
NSN/Nomenclature	•	•	•
Cost	•	•	
Weight/Cube		○	•
Source Maintenance Recoverability Code	•	•	•
Combat Essentiality Code	•	•	•
End-item Application		•	•
FAILURE RATE DATA			
Demand	•	•	•
Operational Failure Rate/MTBF		○	○
PIPELINE DATA			
Order Ship Time	•	•	
Repair Rate	•	•	
Washout Rate	•	•	
Repair Cycle Time	•	•	
DEPLOYMENT DATA			
Environment			○
Climate			○
Intensity Rate			○

•=REQUIRED ○= OPTIONAL

Table 3. Availability- and Demand-Based Sparing Data Requirements

1. Building Detailed Indenture Structures

Indenture structures are important to availability-based sparing because they identify components of end items in terms of their contribution to a system's availability. Without the component indenture structure, allowance mismatches can occur that directly affect system readiness. An example is stocking a high dollar reparable, such as an engine, but not a low cost critical sub-component to that reparable, like an oil filter. This sub-component allowance deficiency could result in lengthy repair turn-around times and consequently impair readiness.

The indenture structure of a weapons system is generally obtained through the acquisition process as part of provisioning data. The Marine Corps uses provisioning data to populate the Applications File, which is a database maintained at Marine Corps Logistics Base, Albany, Georgia. It contains end-item configuration data and indenture relationships, but currently the Applications File only provides a single level of indenture; that is, it only associates a repair part to its end-item, not the subassemblies and items in between [Ref 1]. Alternatively, a full scale implementation of availability-based sparing requires repair parts to be associated with their next higher assemblies and multiple levels of indenture are often required to account for all the reparables and critical consumables associated with a system or end item. For example, ARROWS, one of the Navy's availability-based models, allows for six levels of indenture.

How can the Marine Corps move from one to multiple levels of indenture? Although indenture structure information currently exists within end-item technical manuals, the current formats make such information difficult to extract. Clearly, with thousands of Marine Corps end-items, each containing thousands of parts, converting such information to electronic format is not a trivial task.

One approach is to limit availability-based sparing to a prioritized set of components. For instance, because availability-based sparing is most applicable to decision making with regard to reparables and critical consumables, there is no need to document indenture structure information on the thousands of piece parts. To economically implement a detailed indenture structure the following six steps can be performed.

1. Prioritize End Items. For the purpose of cost tradeoffs given budget constraints, it is important to assess the combat value of end items relative to one another. Prioritizing the combat value of end items for availability-based sparing can be accomplished by using current Marine Corps classifications of end item importance as described in Marine Corps Bulletin 3000 [Ref 14]. There are roughly 1,000 end-items in the Marine Corps inventory [Ref.15]. 18% of these end items are deemed Combat Essential Items [Ref 16]. We suggest that Combat Essential end items serve as the highest priority candidates for availability-based sparing.

End items can also be prioritized by mission. This is especially useful for deployments or exercises where the mission is known. For example, a humanitarian assistance operation may depend heavily on the use of 5-ton trucks, whereas a combat mission depends more on light armored vehicles. Therefore, 5-ton trucks could be spared to a higher availability than other equipment for the humanitarian mission, and vice versa for a combat mission. A methodology for assigning mission/scenario type values was explored by Laforteza [Ref. 17].

2. **Identify Critical Repair Parts for the Highest Priority Systems.** Once the criticality of each end-item is established, the criticality of its repair parts must be established. Part criticality is contained in the CEC data field of SASSY's Technical Data file[4]. This would suggest that repair parts with CEC 5-6 be spared with availability-based models because of the deadlines associated with the corresponding end items. All other CEC items could be spared with demand-based methods. Such an approach could mitigate the more onerous data requirements of availability based sparing. It should be noted that CEC coding is not perfect. There are instances where critical repair parts are not coded correctly, but absent better information, this approach makes sense.

3. **Coordinate with the Military Services.** The Army is in a similar position as the Marine Corps with regards to indenture structure. The Army developed availability-based models without indenture structure but it realizes that including indenture structure in models would generate better stocking decisions [Ref 8]. Ideally, the Marine Corps and the Army should coordinate efforts to their mutual benefit. Equipment managers at the Marine Corps Logistics Base in Albany could coordinate with their Army counterparts for equipment that is common to both Services. Ivancovich et al. [Ref. 1] suggest that the Marine Corps coordinate with the Primary

[4] SASSY has several different database files to include Inventory file, Applications file, and Technical Data file.

Inventory Control Agency of weapon systems that are common to other Services to identify indenture structure information already captured.

4. Search Technical Manuals for Indenture Relationships. Indenture structure information currently exists in equipment technical manuals in the form of diagrams and maintenance instructions to effect repairs. This indenture structure information needs to be extracted and translated into a hierarchical listing by maintenance experts for use by an availability-based sparing model. After this information has been extracted from technical manuals and formatted for availability-based sparing input, it should be validated by maintenance experts for accuracy.

5. Establish a Feedback Mechanism. Central management of indenture structure information facilitates the consistency and accuracy of information. This can be accomplished by Equipment Managers located at the Marine Corps Logistics Base in Albany. To avoid problems with isolation that can occur through such centralized information management, it would also be important to establish a feedback mechanism to operational units' maintenance personnel, who could suggest necessary corrections to the indenture structure. A preformatted form or online feedback mechanism could facilitate the timely update of indenture structure information.

6. Control Data Requirements. To prevent from having to go through the tedious process of extracting indenture structure information from technical manuals in the future, a policy of acquiring indenture structures as logistical data requirements for newly fielded equipment could be implemented. The additional cost of such contracted data represents a small investment likely to be returned many times over through more cost-effective sparing decisions.

2. Indenture Structure Requirements for Limited Availability-Based Sparing Implementation

As an interim step to building a complete detailed indenture structure the Marine Corps could instead construct a two level indenture list of critical consumables and reparables. Specifically, using the single level indenture structure now resident in the Applications File, a listing of critical consumables and reparables can be generated for each end-item. Maintenance experts could then build parent-child relationships between critical consumables that are associated with each reparable. This would produce an indenture structure very similar to the detailed indenture structure described in the previous section, but at substantially reduced cost.

Notice from Table 3 that we list indenture structure as an optional data requirement for availability-based sparing. Although it is one of the more important optional requirements, it is not mandatory. In other words, the Marine Corps could implement availability-based sparing even with its current single level indenture structure. It can accomplish this by separating repair parts into groups (e.g., communications parts, vehicle parts, weapons parts etc.) and then spare each group to a targeted fill rate. Sherbrooke [Ref. 13] writes:

> There are applications where parts hierarchy is unknown.... and it may be able to classify items into different essentiality groupings.... Furthermore, it would not be possible to compute a meaningful availability....instead the managers rely on various fill rate targets by item essentiality class.

This is essentially what the Army does with its OSRAP model that we describe in the next chapter [Ref. 8].

Using a single level indenture structure instead of multiple indentures is sub-optimal to the availability based model because cost-tradeoff decisions between reparables that have multi-indenture relationships are no longer possible. Specifically, repair cycle times for lower indenture reparables are no longer factored into the repair cycle time of higher-level indenture items.

3. Combat Essentiality Codes

Ivancovich et al. [Ref. 1] found major discrepancies in CEC codes between the SASSY Technical Data file and Applications File. Specifically:

> As the Marine Corps proceeds to implement RBS we make the following recommendation....Overhaul the component-level criticality and mission-essentiality codes.

The Marine Corps, regardless of sparing model, should reconcile the differences between the Technical Data file and Applications File to improve the integrity of CEC codes. The criticality code requirement for availability-based sparing is the ability to distinguish between parts that contribute to the availability of an end item, and those that do not. Although any model would benefit from more accurate codes, we believe the current structure of CEC codes is sufficient for availability-based sparing because it distinguishes between critical parts that deadline equipment and non-critical parts that do not. For modeling purposes, a simple approach is for those items with CEC 5-6 to be availability-based spared, and all other CEC items be spared with demand-based methods.

4. Reliability Block Diagrams

We briefly mention Reliability Block Diagrams (RBDs) because there is an availability-based sparing implementation that successfully uses RBDs [Ref. 10]. RBDs are a means of considering the importance of a part to the reliability of the system. An RBD is a logic diagram, which, by means of the arrangement of blocks and lines, depicts the effect of an item's failure on a system's functional performance. We categorize this data element optional. It is a data element used in running simulations and would be appropriate in the provisioning process to show tradeoffs between a system's reliability and supportability. The Navy extensively uses RBDs in its RBS Workstation program.

B. FAILURE RATE DATA

1. The Mean and Variance of Demand

The *demand* for a repair part is the number of failures recorded in a maintenance system or the number of hits in the supply system for that part. Historical demand is one of the most important data elements for forecasting future requirements. It is important to record both the mean and variance, because these statistics help determine the appropriate probability distribution used for forecasting future demand. Generally speaking, low demand rates require a Poisson distribution, and high demand rates require the normal distribution. Variance of demand is important because for low demand rates a high variance to mean ratio generally indicates that the negative binomial distribution is a better predictor of demand than Poisson (See Sherbrooke [Ref. 13] for a full discussion). For our purposes, we require that Marine Corps logistical systems record both mean and variance of demand. Currently both SASSY and MIMMS do so.

There are two types of failure rates: demand failure rates and operational failure rates. Demand failure rates are utilized in current demand-based sparing; operational failure rates are suggested for availability-based sparing.

2. Demand Failure Rates

The Marine Corps' two logistical information systems that collect demand data are SASSY and MIMMS. SASSY demand is used to forecast consumable inventories, while MIMMS demand is used to forecast reparable inventories. MIMMS demand data is designed to flow through and be captured by SASSY. Therefore, the two files are designed to be equivalent.

While attempting to develop operational failure rates, Ivancovich et al. [Ref. 4] compared the demand data between SASSY and MIMMS and discovered that demand captured in one system was completely different from the other. For example, in MIMMS a particular repair part registered 14 failures, while in SASSY, zero failures were recorded. Differences of such magnitude in the files are severe, resulting in a loss of integrity of the data.

A simple solution is for the Marine Corps to use only one system to capture demand data for inventory modeling. For example, the maintenance information system above could serve to capture demand for availability-based sparing. Availability-based sparing is concerned with capturing the demand for actual repairs made to end-items, which represents a closer match with the maintenance information system. In contrast, supply system demand is vulnerable to distortion through various funding cycles, where purchases made are not immediately maintenance related. For example, at the end of the fiscal year, a supply officer with year-end funding available may purchase a stockpile of tires in order to be prepared for a slow down in funding at the beginning of the next year. This year-end bulk purchase bears little relationship to the actual usage and consumption patterns of tires. Worse, the bulk purchase distorts demand variance, potentially causing the wrong probability distribution to be used to estimate future demand. In cases where the variance exceeds the mean, a negative binomial distribution is prescribed for instead of a Poisson distribution [Ref. 13]. Using an incorrect probability distribution will have detrimental affects on the output of the sparing model.

By having the maintenance system record demand, mean and variance calculations should more closely resemble actual maintenance requirements. Efforts can then be concentrated on closing any loopholes that cause maintenance actions not to be recorded. An example of one such loophole currently exists in commercial purchases: commercial purchases obtained through the SMU are not automatically recorded as demand transactions in SASSY.

3. Operational Failure Rates

Demand failure rates described in the previous section do not account for end item density or usage. The term end item *density* refers the quantity of equipment being supported. The term end item *usage* refers to the how much the equipment is utilized (e.g., how many miles a vehicle is driven during an exercise). Operational failure rates offer an improvement over demand failure rates because they do account for these important factors. With operational failure rates, the inventory manager has the capability to forecast demand given changes to equipment density and usage.

Operational failure rate is demand divided by respective end-item usage and density. How usage is specified, and therefore how operational failure rates are measured, depends on the type and use of the repair part, that is, the usage that most accurately reflects the cause of wear and failure of the part. For example, mileage may be the most appropriate usage measurement for tires, whereas hours of operation may be the most appropriate measurement for headlamps. Even within the major assemblies of an end-item, the measurement of usage may vary. Hours of operation may be the appropriate measurement of usage for most components of a vehicle engine, but the number of starts is a more appropriate measurement for the engine's starter. In an ideal situation, operational failure rates for the components of an end-item would reflect these different measurements of usage. Currently it is impractical to achieve this level of detail, but capturing a primary measurement of usage on the end-item is a first step to calculate operational failure rates. For example, the operational failure rates for the components of a vehicle may all be measured in terms of mileage. [Ref. 4]

MIMMS has the capability to capture end-item usage: mileage for vehicles, shots fired for weapons, and hours of operations for major nonvehicular items like generators represent clear examples. This information is entered by a mechanic each time an equipment repair order (ERO) is filled out to effect repairs. However, Ivancovich et al. [Ref. 4] identified data inaccuracies while analyzing equipment usage data. When they looked at end-item usage (mileage for HMMWVs) the mileage was incorrectly recorded on equipment repair records, called Equipment Repair Orders (EROs). For example, the total miles on many vehicles showed a decrease over time.

Information technology can help in this area. Currently, end-item usage is entered by a mechanic manually filling out an ERO. Often the ERO is completed in an office separate from the maintenance shop floor causing a time lapse before the information is recorded. Additionally there is no check to ensure the information is entered correctly. This problem could be corrected by automating the ERO process via computer terminal on the shop floor, with the entire repair history of the end-item recorded in a database and made accessible as soon as the ERO is entered electronically. With this, end-item usage could be instantly validated.

Williamson et al. [Ref. 3 pg. 5] assert that availability-based sparing cannot be implemented without operational failure rates. While operational failure rates are preferred, because they account for end item density and usage, demand failure rates can be utilized with availability-based models. As an example, the Army's availability-based implementation OSRAP uses demand failure rates [Ref. 8].

C. PIPELINE DATA

Pipeline refers to the movement of a failed item through the repair or resupply process. The length of time it takes to receive a part from the source of supply is called the Order Ship Time (OST). The length of time it takes to repair a part is called Repair Cycle Time (RCT). The longer it takes to get a part through the pipeline, the more parts have to be stocked to maintain availability. Consumables have only one component of pipeline data, OST. Reparables have two components of pipeline data, OST and RCT. The Marine Corps' current logistical information systems collect OST for all repair parts and RCT for reparables only.

Ivancovich et al. [Ref. 1] assert that RCT must be collected for all repair parts in order to implement availability-based sparing. However, it is likely that RCT for consumables is minimal and therefore can be ignored. Sherbrooke [Ref. 13] supports this conjecture:

> For inexpensive items, which are seldom reparable...the average depot pipeline time is the procurement lead time rather than the depot repair time for such consumable items.

With this assumption, the Marine Corps' current logistical information systems collect the necessary pipeline data to implement full and limited availability-based sparing. The assumption that consumable repair cycle time is insignificant could be validated by conducting an analysis of repair cycle times for consumables and reparables at Marine Corps intermediate repair activities.

D. DEPLOYMENT DATA

Previously we have not distinguished between sparing requirements in garrison and sparing requirements for deployments. Because the Marine Corps is an expeditionary organization, it is important to discuss the differences that might exist between garrison and deployed sparing requirements. The stocks of Class IX repair parts needed in a garrison often differ significantly from those needed for a contingency operation because the operational environments are different.

In garrison, where OST and historical demand data are easily obtained, readiness and deployability are important, but cost is a critical consideration. By contrast, in a deployed scenario, OST is unpredictable, historical demand data are usually less useful than in the garrison, and, while cost is considered, readiness and deployability are paramount. Maintenance capability is also likely to be much greater in garrison, which results in the requirement to stock more reparables in a deployed environment.

The Marine Corps can benefit from an inventory sparing methodology that allows for both garrison and contingency operations using optimizing methodologies in a user-friendly environment. Availability-based sparing methodology allows the manipulation of variables that distinguish between operations in garrison or while deployed. This allows an availability-based sparing methodology to be used seamlessly whether deployed or in garrison.

Several initiatives to improve the current process of building deployed blocks in the Marine Corps are underway. The following is a review of how the Marine Corps currently builds deployed repair parts blocks.

1. Current Procedures for Building Deployed Parts Blocks

First, an equipment density list (EDL) is submitted and run against the SASSY demand file creating a list of all repair parts ordered in the past year against items on the EDL. This listing is then filtered for critical repair parts using CEC codes. This final product, called a GENPAC, shows the Marine Expeditionary Force (MEF) demand data for all the critical NSNs (CEC 5&6) that have been ordered against the end-items listed on the EDL. The size of the deploying unit is then compared against the size of the MEF. The MEF demand quantity is prorated to the size of the deploying unit. The GENPAC is then reviewed manually by maintenance personnel for any additions or deletions. Finally, the GENPAC is approved and the Deployed Units section of the SMU builds the parts block.

Shortcomings with the current process are (1) end item usage is not accounted for in the sparing process, (2) historical demand is garrison based, and (3) equipment readiness is an uncontrolled output.

2. Maintenance Deployment Commodity Planning Tool

The Naval Facilities Engineering Service Center in Port Huenume, California is currently conducting a research and development project called the Maintenance

Deployment Commodity Planning Tool (MDCPT). The MDCPT will allow the Marine Corps planners to use data from past exercises and operations to develop Class IX spare packages.

The MDCPT suggests the following procedures to build a parts block. In addition submitting an EDL, Marine Corps planners would submit a document that profiles the type of operation for which the parts block is being built. Input parameters would include environment (sea-based, shore, or both), climate (desert, jungle, temperate, mountain, cold, frigid, polar), interval (length of deployment), type (operation, exercises), event (MEU, CAX, JTF), location (CONUS, OCONUS), and echelon (maintenance capability).

After completing the mission profile, a parts block would be built utilizing availability-based sparing techniques outlined by Laforteza [Ref. 17]. During the deployment, demand data would be captured and stored in a Common Data Repository (COMDAR). At the conclusion of the operation, planners validate the profile information submitted prior to the exercise. For example, prior to the exercise, if the input climate was jungle, but the actual exercise was conducted in the desert, the profile would be updated to reflect the desert climate. The demand data would then be stored in the COMDAR under that mission profile. Over time, sufficient demand data could be captured to allow parts blocks to be built based on demand data from specific operations, deployments, and exercises.

For deployments, it is especially important to use operational failure rates instead of demand for availability-based sparing. Demand failure rates are only useful in a steady state environment, where the extent, duration, type of end-item usage, and end-item density does not vary. While it is reasonable to assume that equipment density and duration are constant, the operational usage of the equipment can vary greatly from deployment to deployment. Therefore, it is important to account for these variances by using operational failure rates when building future parts blocks. To capture operational failure rates it would be necessary to quantify the usage of equipment. As described earlier, usage readings include mileage for vehicles, rounds fired for weapons systems, and hours of operation for major nonvehicular end-items such as generators. By capturing demand data and equipment usage, an operational failure rate can be calculated.

Marine Expeditionary Units (MEU) provide an ideal opportunity to implement the capturing of operational failure rates. MEUs are the Marine Corps' standard deploying units that embark on ships and typically deploy for six months at a time. With equipment density and demand already captured, equipment usage, the final data element necessary for calculating operational failure rates, could be captured by recording equipment's beginning and ending usage measurements. This could be done manually at first. Equipment information such as serial numbers, weight, and cube are already captured for the Marine Corps embarkation program MAGTF Deployment Support System II (MDSS II).

Eventually the process of capturing end item usage could be automated. Equipment information is captured and translated into bar-coded labels that can then be attached to the equipment. The equipment is scanned during embarkation and debarkation to assist in total asset visibility. One of the data elements that could be scanned is equipment usage. A sensor device could be configured to allow for the capturing of this information.

E. SUMMARY

The Marine Corps does not collect the data necessary to fully implement availability based sparing, specifically indenture structure and operational failure rates are data deficiencies. We suggest changes to information systems to allow for their capture in the future. However, the Marine Corps does collect the data requirements to implement availability based sparing on a limited basis. A limited implementation involves the use of a single level indenture structure categorized into essentiality groupings spared to targeted fill rates. Demand failure rates are used in place of operational failure rates until such a time that operational failure rate data has been collected. MEUs provide an ideal opportunity to begin capturing operational failure rates because their equipment usage can be captured at the beginning and end of each deployment. Equipment usage is then combined with equipment density and demand to calculate operational failure rates.

IV. CURRENT IMPLEMENTATIONS OF AVAILABILITY-BASED SPARING

We consider two retail availability-based sparing implementations for potential adoption by the Marine Corps: ARROWS used by the Navy, and OSRAP used by the Army. Although other availability-based sparing implementations are also currently used in the Services, these two are retail-intermediate implementations as required by the Marine Corps. ARROWS and OSRAP differ considerably with respect to data requirements. ARROWS is a comprehensive availability-based sparing implementation that utilizes all the data requirements described in the previous chapter (i.e., required and optional). Alternatively, OSRAP uses only the minimum data requirements necessary to run the availability-based model. Even with its current data capturing capabilities, the Marine Corps could implement OSRAP immediately.

A. ARROWS

The Aviation Retail Requirements Oriented to Weapon Replaceable Assemblies (ARROWS) model, is a readiness-based sparing model for developing retail level inventory requirements. The model computes and evaluates spares and repair part requirements for secondary items stocked in support of aviation weapon systems. [Ref. 18]

ARROWS produces a list of parts required to keep a group of equipment operational. Data requirements for the model include an indenture structure, price, failure rate, repair cycle time, and end-item usage. In addition to embedded availability-based sparing algorithms, ARROWS also includes demand-based algorithms for the non-mission essential or low cost parts.

As with all availability-based methods, ARROWS starts with the first unit of every part that makes up a weapon system and estimates how much the weapon system availability could be increased by including that particular part in the list of spares. It then compares the cost of each item and determines which items give the largest increase the weapons system availability per unit cost. The model computes this ratio for every item of stock between some predetermined maximum and minimum quantity. It then ranks the parts' relative availability-cost ratios and sums the total cost and the availability of the weapon system for each unit of stock.

ARROWS can handle up to twenty weapons systems, fifty sites, and six levels of indenture. It also has three different methods for computing spares: an availability-based sparing algorithm for high dollar and critical reparables; an awaiting parts algorithm for all other secondary reparables and critical consumables to minimize the amount of time the high dollar reparables await parts; and a demand-based sparing optimization for the non-mission essential, low cost parts for which availability-based sparing data maintenance would not be cost effective.

The type of availability-based sparing ARROWS represents could greatly enhance the Marine Corps inventory management process, but its adoption would require the Marine Corps to build a detailed indenture structure, capture operational failure rates, and prioritize the weapons systems that it wants to analyze with availability-based sparing. These requirements present a considerable investment in focus, time, and money.

B. OSRAP

Prompted by the logistics planning requirements of Operation Desert Storm, the Army Material Systems Analysis Activity (AMSAA) developed a methodology based on the availability-based sparing approach to generate stockage lists for each supply echelon. This methodology includes techniques to estimate requirements for both combat damage and reliability failures. The model developed to support this approach became known as the Optimum Stock Requirements Analysis Program (OSRAP) [Ref 8].

OSRAP incorporates a version of availability-based sparing, in which the cost, weight, or volume of parts is minimized and weapon system operational availability or readiness is maximized. The idea is to stock an appropriate group of repair parts to maintain a weapon system or end-item at a specified readiness level.

In order to produce the appropriate parts package, several parameters must be supplied: OST, unit price of the part, repair cycle time, mean time to repair, and level of repair. For contingency or Operations other than War (OOTW) environments, resupply characteristics and weapon system densities are required. The user is also able to enter a usage modifier to simulate increased operating tempo, or default values for these parameters can be used.

Because OSRAP uses a single indenture list and demand from legacy supply systems instead of operational failure rates, the effort required for the Marine Corps to employ OSRAP techniques are likely to be minimal.

Seibert [Ref. 8] describes benefits of such OSRAP adoption in terms of cost, equipment readiness, supply performance, and mobility. These projected benefits are the result of field demonstration studies conducted in 1992-93 by both the Fifth Infantry Division (5th ID) and National Training Center (NTC). Seibert reports that inventory investment was significantly reduced. NTC inventory investment was reduced from $140.2 million to $89.2 million. 5th ID inventory investment was reduced from $76.5 million to $70.7 million.

Readiness and supply performance indicators also improved with availability-based sparing. At both demonstration sites, equipment readiness, as measured by Equipment Mission Capable (EMC) and Non-mission Capable Supply (NMCS) rates, improved or remained steady. NTC EMC rates improved from 66 percent to 82 percent, while 5th ID maintained its 94 percent rating. NMCS rates improved at NTC from 9 to 6 percent, and at 5th ID the rate improved from 5 to 4 percent. Additionally, supply performance indicators improved with availability-based sparing methodology. Fill rates improved at NTC by 58% and by 16% at 5th ID.

The impact of availability-based sparing on the footprint of the parts block was also measured for 5th ID. Using OSRAP instead of demand-based techniques, the block's footprint decreased from 122,651 cubic feet to 75,120 cubic feet. The weight of the block decreased from 3.67 million to 1.63 million pounds. The number of unique repair parts increased, however, from 8,483 to 10,335.

The performance improvements realized by the Army suggest the Marine Corps could expect good results from implementing this type of methodology. Moreover, the Marine Corps has the data collection capability required to implement OSRAP immediately.

V. CONCLUSIONS AND RECOMMENDATIONS

Leverage Often Comes from New Ways of Thinking

- *Peter Senge [Ref 19]*

DoD has mandated the use of availability-based inventory models. Availability based sparing offers many advantages over its demand-based counterpart, but the former also exacts more onerous data requirements. With the exception of the Marine Corps, each Service has implemented availability-based sparing models to varying degrees. But implemented models are currently available that could enable the Marine Corps to implement availability-based sparing on a limited scale without a severe burden on its current data capturing capabilities. Further, availability-based models implemented for both the Army and the Navy are available for adoption by the Marine Corps. The Army model, OSRAP, is also compatible with current data collection systems in use by the Marine Corps. These results lead to a number of conclusions and recommendations.

A. CONCLUSIONS

Although the Marine Corps must improve its data capturing capabilities in order to take full advantage of availability-based sparing's benefits; it can achieve a limited scale implementation now. The first step is consolidating the management and budgeting of reparables and consumables, which can be effected immediately. Secondly, parts are separated into two categories: reparables and critical consumables, and piece parts. Stocking levels for the former can be determined by using availability-based sparing, while levels for the latter can be determined using current demand-based sparing models. By using both models in a complementary manner, the Marine Corps can obtain the benefits of availability-based sparing at a manageable cost.

In the absence of detailed indenture structure, the Marine Corps can develop a two level indenture structure with the Applications File, by matching critical repair parts with the associated reparables. If this proves infeasible, then even a single indenture implementation can be effected by categorizing repair parts into essentiality groupings and sparing them to targeted fill rates. Instead of preferred operational failure rates that account for end item usage and density, currently captured demand failure rates can be used as the Army does with OSRAP. The Marine Corps' current data capturing capability for pipeline data is sufficient for both limited and full scale implementations.

B. RECOMMENDATIONS

The first recommendation is to adopt OSRAP techniques and implement limited availability-based sparing. The Marine Corps' standard deploying organization, the Marine Expeditionary Unit, offers a well-developed structure on which an implementation can be tested utilizing the procedures described in Maintenance Deployment Commodity Planning Tool.

To fully implement availability-based sparing, the Marine Corps will need to develop detailed indenture structures. Such structures are imperative to make stocking tradeoff decisions between reparable and consumables. Although some benefits can be derived from availability-based sparing with a single indenture structure, as in the Army's OSRAP implementation, we recommend proceeding to a full availability-based sparing implementation such as ARROWS. We recommend that indenture structures be managed centrally at the equipment manager level with mechanisms for feedback from the field.

We noted problems experienced by the Marine Corps with capturing demand to calculate accurate operational failure rates. Based on the data and operations, we recommend the maintenance logistical information system be used exclusively to capture demand data and calculate operational failure rates. With one system to capture demand for all maintenance actions, improved data integrity should result. Also current loopholes in demand capturing, for example commercial purchases that do not register demand, need to be addressed.

The Marine Corps also needs to improve the capturing of end-item usage so that accurate operational failure rates can be calculated. MIMMS captures end-item usage sufficient for calculating operational failure rates, when the data are accurate. The problem is that data are often inaccurate because no error correction exists at the time of input to ensure the data is valid. We suggest that maintenance records of equipment be recorded electronically on the maintenance shop floors instead of manually. This would allow a database containing the entire history of repairs for each end-item to be accessible when the electronic equipment repair order is completed.

With such a system in place, the integrity of mileage, shots fired, or hours of operation should improve so that operational failure rates could be accurately calculated.

Finally, we also recommend further research in a number of areas: Research that looks at how to optimally allocate funding between the demand-based and availability-based groups is necessary. We offered a simple solution, suggesting that the inventory manager could graphically evaluate cost-availability/fill rate curves to make funding allocations. More robust mathematical techniques are needed.

The two Marine Corps logistical information systems (SASSY and MIMMS) that supposedly capture equivalent demand do not. We suggest that the MIMMS is the ideal system to capture demand because availability-based sparing is concerned with capturing demand for actual repairs made to end-items. Further research is necessary to reconcile demand-recording discrepancies between SASSY and MIMMS.

The process of capturing end item usage could be automated. Equipment information is captured and translated into bar-coded labels that are attached to the equipment. The equipment is scanned during embarkation and debarkation to assist in total asset visibility. One of the data elements that could be scanned is equipment usage. A sensor device could be configured to allow for the capturing of this information. The capturing of operational failure rates is critical to availability based sparing. Operational failure rates, which are critical to full scale implementation of availability-based sparing, cannot be calculated until end item usage is captured.

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